Very Shallow Water Computer Aided Detection / Computer Aided Classification For Mine Countermeasures

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LONG-TERM GOALS

The long-term goal of this project is to develop automated sea mine detection and classification algorithms for imaging sonars carried by unmanned underwater vehicles (UUVs) operating in the very shallow water (VSW) region. This technology is one of the enablers for autonomous mine countermeasures (MCM) operations in the VSW, and will permit Navy divers and marine mammals to be removed from this extremely hazardous task.

OBJECTIVES

The objective of this task is to demonstrate automated sea mine detection and classification in the VSW, using Computer-Aided Detection, Computer-Aided Classification (CAD/CAC) algorithms recently developed by CSS, Raytheon, and Lockheed Martin (LM). The initial VSW system targeted for the transition of this technology is the Woods Hole Oceanographic Institute (WHOI) Remote Environmental Monitoring Units (REMUS) UUV, which carries a MSTL side-scan sonar. In FY00, the CAD/CAC processing will be accomplished post mission, and in FY01, CAD/CAC processing will be completed real-time in the REMUS UUV.

APPROACH

Our approach is to fuse detection results from three CAD/CAC algorithms. One was developed by CSS (Gerald J. Dobeck) and the second by LM, Syracuse, (Tom Aridgides and Manny Fernandez), both under ONR Program Element 0602315N MCM Mining & Special Warfighting Technology (sponsor: ONR 321W). See references below. The third algorithm was developed by Raytheon (lead by Chuck Ciany) under the AQS-20 program for PMS 210.

The fusion of algorithms is a very powerful paradigm. Each algorithm acts as an expert looking at the same data with a different perspective (like getting a medical opinion from several specialists). Each algorithm is based on different mathematical, statistical, and geometric theory, and thereby emphasizes (or de-emphasizes) different characteristics of the data. Therefore, much can be gained through their fusion; especially in false alarm reduction, where few false alarms are common to all algorithms.

The three CAD/CAC algorithms are substantially different, and their synergy, when fused, should prove very beneficial. CSS's approach is based on a nonlinear matched filter detector, an optimal feature-selection method, a probabilistic-based neural net classifier "anded" with a linear discrimination classifier. LM's approach is based on an adaptive-clutter filter detector, a feature-vector orthogonalizer, and generalized log-likelihood classifier. Raytheon's approach is based on an adaptive highlight/shadow image segmentor, a feature extractor, and a feature-vector scoring-method for classification.

Based on this CAD/CAC/Fusion technology, post-mission analysis (PMA) software tools were developed. These software tools are referred to as PMA2000 (see Figure 1).

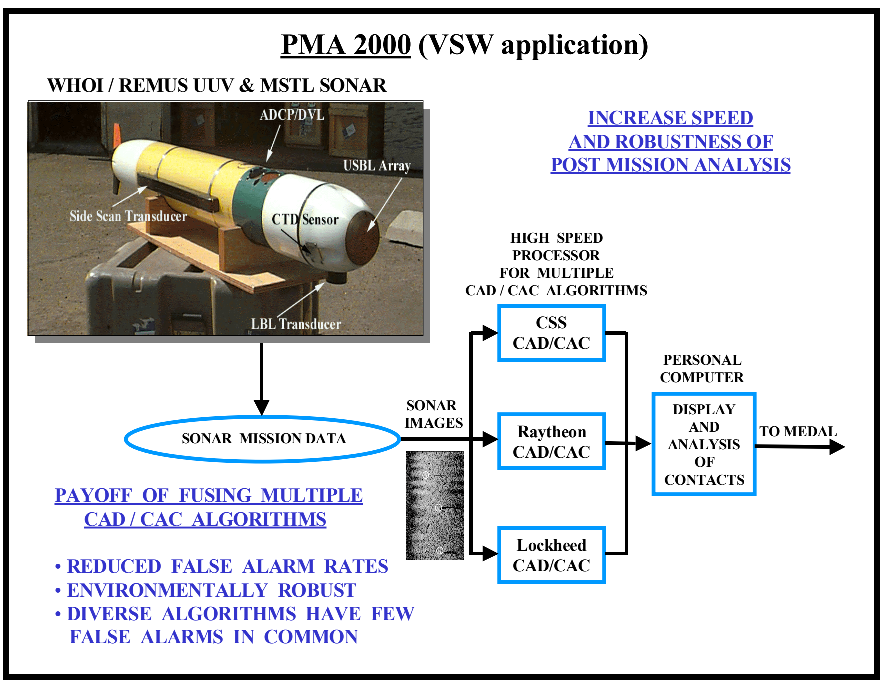

Figure 1. PMA2000

The PMA2000 process has two stages: the CAD/CAC stage and the Fusion/Review stage. The first stage is fully automatic. Here all the sonar data is processed by the multiple CAD/CAC algorithms, each of which detect mine-like objects in the sonar data. This stage is executed on a high-speed Dec/Alpha workstation, which typically processes the sonar data about 8 times faster than real-time (In the future, this stage can be run on the sonar platform in real-time). Information on each of the CAD/CAC detections, including image snippets and the locations of the detected objects, is sent to the

Fusion/Review stage, which runs on a personal computer (PC) or laptop. In this second stage, the operator chooses a fusion rule that identifies the objects to which he wants to restrict his review (e.g., select only those detected objects that were detected by at least two CAD/CAC algorithms). The selected objects are displayed to the operator, who reviews them in detail for their mine-like quality and culls out any false alarms. The review-stage software allows the operator to measure the object's and shadow's size, magnify the object, and observe the pattern, shape, and density of potential mine lines on a Latitude/Longitude map. Finally, the operator prepares the list of mine-like contacts, which is distributed to the Fleet over the C4I network. The PMA2000 Fusion/Review software has been designed so that the operator can rapidly review about 100 detections in less than 10 minutes.

WORK COMPLETED

During the first quarter of FY00, more sophisticated methods were developed to fuse the scores from the three CAD/CAC algorithms that, hopefully, would significantly outperform simple logic-based fusion rules. In the past, only simple logic-based fusion rules were used; e.g., (1) select only those objects that were detected by two or more CAD/CAC algorithms, or (2) select only those objects that were detected by all three CAD/CAC algorithms. Three new fusion methods were developed: (1) CSS developed one based on the Fisher Discriminant, (2) Raytheon developed a second based on three-team OR-ing with optimized thresholds, and (3) LM developed a third based on the log-likelihood ratio test. These new fusion methods were evaluated using the SAHRV Field Evaluation Two (FEII) Test data (September 98, San Diego). Three papers were written for SPIE AeroSense 2000, describing these methods (see References).

In the 2nd quarter of FY00, data was received from the SAHRV Field Evaluation Three (FEIII) test (October 99, San Diego). This data was ground-truthed and used with the FEII data to tune the CSS, LM, and Raytheon CAD/CAC algorithms in preparation for the June Fleet Battlelab Experiment-Hotel (FBE-H) Rehearsal test in Fort Lauderdale.

In June, the CAD/CAC team participated in the two week FBE-H Rehearsal test.

In July and August, the CAD/CAC team prepared for FBE-H off Panama City, FL using data collected during the June Rehearsal test to fine tune their CAD/CAC algorithms.

The CAD/CAC team participated in FBE-H (25 August to 7 September).

RESULTS

The results of the new fusion methods are shown in Tables 1 and 2 for the FEII data (containing 80 targets in 562 images, corresponding to an area of about 670 meters by 670 meters).

Table 1. Standalone CAD/CAC and AND-ing Results for FEII Test Data

	PdPc	False Alarms in 562 Images
CSS Standalone	93.0% (75/80)	205
Raytheon Standalone	90.0% (72/80)	697
LM Standalone	96.3% (77/80)	1146
Simple AND-ing	81.3% (61/80)	41

Comparison of Tables 1 and 2 shows the benefit of algorithm fusion for dramatically reducing false alarms while preserving a high probability of detection and classification (PdPc). Also shown is the improvement of the new fusion methods over the simple AND-ing. More details can be found in the references below.

Table 2. Fusion Results

PdPc	False Alarms in 562 Images (about 670 meters by 670 meters)		
	CSS fusion method	RAY fusion method	LM fusion method
98.8% (79/80)	126	156	123
95.0% (76/80)	90	91	60
90.0% (72/80)	59	57	52
85.0% (68/80)	45	44	40
80.0% (64/80)	40	39	33

The results from FBE-H were excellent. During post mission analysis, the CAD/CAC algorithms processed the data 10 times faster than real-time. Despite having trained the CAD/CAC algorithms with data from the difficult coral-reef environment at Fort Lauderdale, the performance derived from algorithm fusion was remarkably good, even though the standalone performance of the individual CAD/CAC algorithms was quite unacceptable. The "any 2" fusion rule was used for FBE-H; i.e., select only those objects that were detected by two or more CAD/CAC algorithms. Seven REMUS missions were conducted; for the larger missions, about 500 images were collected, covering about 1000 meters by 1500 meters. The CAD/CAC stage of PMA2000 processed a 6-7 hour REMUS mission in less than 30 minutes. The Fusion portion of PMA2000 typically selected about 100 objects for review. Using the Review portion of PMA2000, the operator was able to quickly review the 100 objects and cull out any false target in less than 10 minutes.

An AQS-14A Fleet operator from the AMCM helicopter squadron, HM-14, in Norfolk, VA, was brought in by ONR to evaluate PMA2000. OS1 Brett Dean was given brief training using mission 1 data. He then processed missions #2, 3, 4, 6, and 7 on his own. His very favorable review includes these comments, "Overall very successful, PMA2000 station performed exceptionally well. A very successful demonstration with exceptionally useful applications." For all seven REMUS missions, the PMA2000 process found 50 out of the 57 mine-like objects identified by the operators. The missed objects were caused by unique side-lobe and long-range characteristics of the REMUS sonar. Modifications to the CAD/CAC algorithms will be made in FY01 to compensate for this.

IMPACT/APPLICATIONS

The CAD/CAC technologies from this project will allow the mine reconnaissance mission to be performed remotely by the REMUS UUV, removing diver/mammal teams from the hazards posed by underwater mines, while also enhancing covertness and reducing time required for locating mines.

TRANSITIONS

The principal transition for this project is the Pre-Planned Product Improvement program for the REMUS/SAHRV system, sponsored by PMS325J. Other transitions that are possible for this CAD/CAC technology include the AQS-20 AMCM minehunting sonar system (PMS 210), the Remote Minehunting System (RMS or AN/WLD-1[V]-1, PMS 407), the Long-term Mine Reconnaissance System (LMRS, PMS 403), and the SQQ-32 minehunting sonar product improvement (PMS 407).

RELATED PROJECTS

Since 1994, CSS, teamed with LM, Draper Lab, and others, has lead the development of algorithms for automated sea mine detection and classification under ONR Program Element 0602315N MCM Mining & Special Warfighting Technology (sponsor: ONR 321W).

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